High and Dry: Trading Water Vapor, Fuel and Observing Time for Airborne Infrared Astronmomy

Jeremy Frank and **Elif Kürklü**∗
NASA Ames Research Center
Mail Stop N269-3
Moffett Field CA 94035-1000
{frank,ekurklu}@email.arc.nasa.gov
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The Stratospheric Observatory for Infrared Astronomy (SOFIA) is NASA's next generation airborne astronomical observatory. The facility consists of a 747-SP modified to accommodate a 2.5 meter telescope. SOFIA is expected to fly an average of 140 science flights per year over it's 20 year lifetime, and will commence operations in early 2005. The SOFIA telescope is mounted aft of the wings on the port side of the aircraft and is articulated through a range of 20° to 60° of elevation. A significant problem in future SOFIA operations is that of scheduling Facility Instrument (FI) flights in support of the SOFIA General Investigator (GI) program. GIs are expected to propose small numbers of observations, and many observations must be grouped together to make up single flights. Approximately 70 GI flight per year are expected, with 5-15 observations per flight.

An important goal of flight planning for SOFIA is to ensure that line-of-sight water vapor (LOS WV) is minimized during observing (Becklin & Horn 2001). This can be accomplished in one of three ways. It has long been known that water vapor decreases with altitude, thus observing at higher altitude reduces LOS WV. If we analyze $\csc(h)$ where h is the telescope elevation in the range $20^\circ \leq h \leq 60^\circ$, we see that it takes on values in the range $[18.5, 56.5]$; thus, choosing the position and time for observing at high telescope elevations reduces LOS WV. Finally, Becklin and Horn (Becklin & Horn 2001) showed that, in general, atmospheric water vapor is lower near the poles; thus, LOS WV can be reduced by repositioning the aircraft.

Unfortunately, there are complex tradeoffs between the takeoff fuel weight, flight duration, percentage of requested observations that can be performed, and LOS WV. During flight, aircraft altitude is limited by aircraft weight. The more fuel carried, the longer the flight, but also the more limited the aircraft's initial operating altitude. Fuel is costly (JPA costing $2.00 a gallon in December of 2004) so using it wisely is important. Furthermore, repositioning the aircraft to seek drier air or maximize telescope elevation will generally require preparatory "dead-legs" (during which no observations are performed); this will reduce time for observing.

The SOFIA Automated Flight Planner (AFP) (Frank, Gross, & Kürklü 2004) enables rapid exploration of the tradeoffs described above. We demonstrated the utility of AFP in a study performed on 19 hours of requested observations for 3 days in December, and 31 hours of requested observations for 5 days in June; both flights originated from Moffett Field, CA. The AFP generated the trade space for 3 different fuel loads and 4 different policies using the telescope elevation to reduce LOS WV. We show that there are tradeoffs between takeoff fuel load, percentage of requested observations scheduled, and line-of-sight water vapor (see Figure 1). We see "inflection points" where the the number of requested observations needed to reduce LOS WV dramatically decreases; these appear to be natural operating points for SOFIA. Flight planning for the previous generation airborne observatory, the Kuiper Airborne Observatory (KAO), was done by hand; annecdotal evidence suggests this required roughly 8 hours to generate one flight plan. The AFP generated 600 flight plans in roughly 50 hours of computation time, a feat beyond the capabilities of human flight planners.

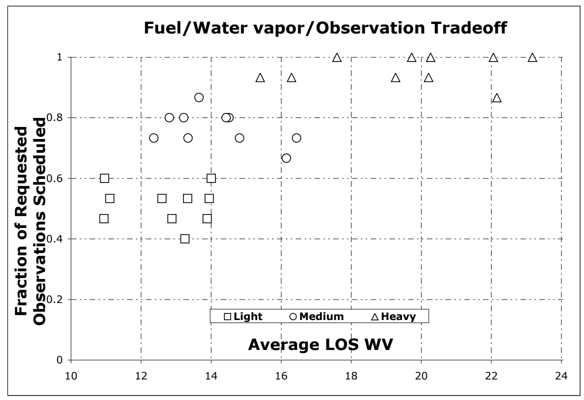

Figure 1: Tradeoff between takeoff fuel load, LOS WV and fraction of requested observations scheduled.

∗QSS Group, Inc.

References

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